SPATIAL AND SPECTRAL RESOLUTION OF A GERMANIUM STRIP DETECTOR

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Abstract. Germanium strip detectors combine both the excellent energy resolution typical of germanium detectors and fine spatial resolution possible in a strip detector. They are applicable to sensitive, high spectral resolution γ-ray detectors using coded-aperture or Compton telescope techniques. Our first detector is in a planar geometry with orthogonal strips on the upper and lower detector surfaces, providing 9 mm spatial resolution. The detector has 5 strips on each surface and an active volume of $45 \times 45 \times 12$ mm. Good spatial and energy resolution are demonstrated.

Key words: Ge detectors, Strip detectors, Gamma-rays

1. Introduction

Radiation detectors that combine good energy resolution with fine spatial resolution are needed to provide spectroscopy and imaging in a single instrument. Device applications in high energy astrophysics include coded-aperture and Compton scatter telescope imaging. Superior spectroscopy is needed to resolve suspected cyclotron features [1; 2], determine annihilation radiation line–width [3; 4], improve sensitivity to narrow-line features in a variety of astrophysical sources, and observe soft spectra. Superior angular resolution is needed to localize unknown sources or to resolve closely spaced sources.

Germanium strip detectors are capable of providing excellent spatial and spectral resolution. Such devices are fabricated from planar germanium by cutting [5], etching [6], and photomask [7] techniques. In a two-dimensional detector, strips on opposite faces are orthogonal (Figure 1).

Readout of the signals from each strip may be achieved in several ways: a capacitive [8] or resistive [9] charge division network may be used to to reduce the number of channels of electronics required. Readout of individual strips provides the best performance. Each strip behaves as a single-channel geramanium detector with excellent energy resolution dominated by the usual factors of detector capacitance, quality of the front-end electronics and electron-hole counting statistics. Cross-talk between the strips can be

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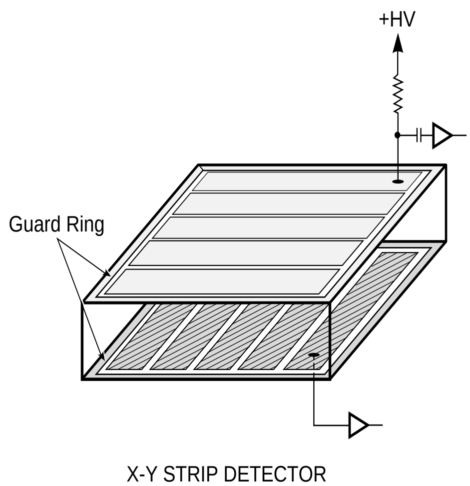

Fig. 1. Schematic of the germanium strip detector used in this work. Crossed electrodes provide two-dimensional position localization of interactions. The electrodes may be read out individually or grouped in two charge-division chains, one for each side, then readout with four channels of electronics (not shown here). The guard ring provides increased immunity to leakage currents. There are 5 strips on each face of the detector, centered on a 9 mm pitch and 45 mm long. The active volume is $45 \times 45 \times 12$ mm.

minimized and calibrated. One- and two-site gamma ray interactions can be uniquely reconstructed.

In an earlier work, we operated a two-dimensional strip detector using two capacitive charge division networks (one network for strips on each side of the detector) and four channels of electronics [10]. This approach did succeed at localizing individual interactions, but with some expected complications. First, energy resolution of the detector is degraded, getting worse with increasing numbers of strips. In our detector, resolution degraded to 5.5 keV for 5 strips in a capacitive charge division network, from 2.2 keV for a single strip. Second, the minimum energy threshold is higher than for single strip operation. Third, multiply interacting gamma rays cannot be located accurately and energy measurements are further degraded by electronic non-linearities in the system.

2. Experiment

The 5×5 strip detector used in this work (Figure 1) was fabricated using a photomask technique to make the lithium and boron implants. Our laboratory data acquisition system consists of 10 spectroscopy channels, each with a 13-bit ADC, permitting strips to be analyzed individually. The ADCs are read out through a CAMAC crate with a Macintosh computer. Events are stored on disk in list-mode for subsequent processing.

A collimated source of 60 keV gamma rays from ^{241}Am was used to investigate the positional response of the detector. The collimated beam is $\sim$1.2 mm in diameter (FWHM) with a triangular intensity profile on the surface of the detector. The position of the beam is controlled by a position table under computer control.

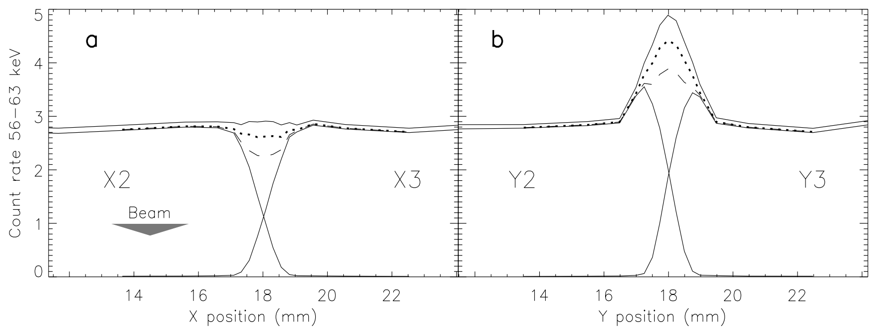

Fig. 2. Detector response *vs.* position for a 1.2 mm diameter (FWHM) collimated beam of 60 keV γ-rays. Figure 2a represents scanning the beam across the boundary between two X-strips (B side). Figure 2b represents scanning the beam across the boundary between two Y-strips (Li side). The γ-ray beam is incident on the Y-side of the detector. The uppermost solid curve shows the count rate on the Y/X strip on the opposite face of the detector (strip parallel to the scan direction). The lower solid curves show the count rates in the two strips identified in the Figures. The lower dashed line is the sum of the rates in the individual strips. The upper dotted line is the rate associated with the energy window applied to the sum of the signals from the 2 strips.

Spatial response between two X-strips and between two Y-strips is shown in Figure 2. The left panel shows a relatively flat response to 60 keV total-energy events over the surface of strip X2, then drops off rapidly to zero at the edge of the strip. Similiary, response of the X3 strip rises as X2 drops. Events that share charge between X2 and X3 are excluded from the individual strip response curves by event selection using a narrow energy window around 60 keV. Therefore, the sum of the individual strip responses (dashed curve) drops between the strips.

About half of the charge sharing events are recovered by summing the signals from adjacent strips. The upper dotted curve in Figure 2a represents the 60 keV window rate in the sum of the two strips. The remaining dip in the response curve is attributed to charge sharing events where the signal in one of the two strips is below our discriminator threshold ($\sim$20 keV), and is therefore not digitized.

Figure 2b shows a similar result from scanning between two Y-strips. The Y-strips are lithium drifted contacts on the upper surface of the detector (toward the gamma-ray source). We estimate that these contacts are currently $\sim$500 μm thick, and represent a dead absorbing layer on the surface above the active volume of the detector. The large enhancement in efficiency between the strips results from a gap between the lithium contacts where the active volume of the detector is closer to the surface.

The width of the charge-division region between strips is estimated. A model of the γ-ray beam crossing over a sharp strip edge is a good descrip-

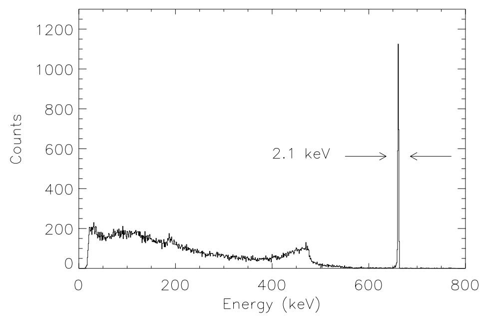

Fig. 3. Energy spectrum from all five strips using conventional room temperature electronics. Energy resolution performance is limited by the high capacitance ($\sim$30 pF) of the wiring and feed-throughs in the detector housing. A uniform illumination of 662 keV gamma-rays was used. Total-energy peak efficiencies of $\sim$1% in a single pixel, and $\sim$2% in an entire strip are observed, consistent with expectations for a detector of this size.

tion of the roll-off in response *vs.* position. In this model, partial energy is collected on a strip if a photon interacts beyond the edge of the strip, and partial energy events are rejected by event selection. We find the true position of the strip edge by moving an assumed position until the model fits the roll-off. This simple model provides an excellent fit to the observed roll-off. Results of fitting adjoining strip edges suggest a gap of $\sim$0.4 mm between both the X- and Y-strips where charge division occurs between the strips. This is consistent with the size of the gap between the electrodes.

Spectroscopy of the strip detector is comparable to conventional germanium detectors as evident from Figure 3.

3. Conclusions

The device tested here demonstrates the desired properties of excellent spectroscopy with good spatial resolution. The narrow gap between strips and sharpness of the edges suggests that future devices with sub-mm imaging are possible. A device with 2 mm strips is currently being fabricated.

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